AD-A044 580 FOREST PRODUCTS LAB MADISON WIS F/G 2/6
EFFECT OF NITROGEN FERTILIZATION ON BLACK WALNUT--GROWTH, LOG Q--ETC(U)
1977 R R MAEGLIN, H HALLOCK, F FREESE
UNCLASSIFIED FSRP-FPL-294 NL

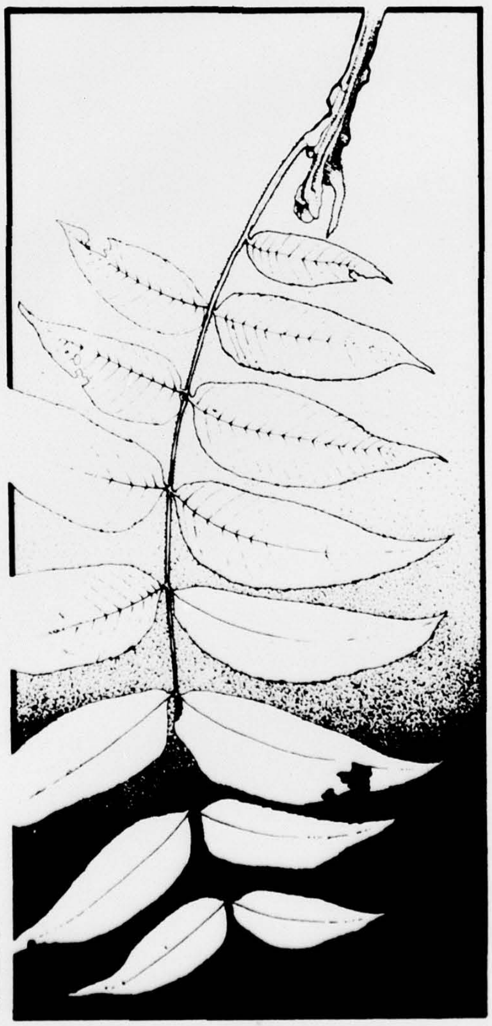
1 OF 1
ADA
044580

END
DATE
FILMED
10-77
DDC

EFFECT OF NITROGEN FERTILIZATION ON BLACK WALNUT-- GROWTH, LOG QUALITY, AND WOOD ANATOMY

USDA FOREST SERVICE
RESEARCH PAPER
FPL 294
1977

U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
MADISON, WIS.



ABSTRACT

Nitrogen fertilizer in the form of ammonium nitrate was applied to two 40-year-old stands of black walnut growing in southern Wisconsin. The stands--one upland and one bottomland--were fertilized in 1965, 1969, and 1972 with 1,500 pounds per acre of ammonium nitrate. On the upland site, fertilized trees increased in diameter growth, but not significantly. On the bottomland site, fertilized trees had significantly lower diameter growth. Upland fertilized trees had significantly fewer new sprouts than did control trees, and bottomland trees had no new sprouts. No loss of net log quality resulted from fertilization. Wood anatomy differences due to fertilizing should not affect wood machining or drying properties. It is recommended that both soil and foliar analyses be made prior to fertilizing black walnut. Sites with high levels of phosphorus and potassium should not be fertilized with nitrogen.

EFFECT OF NITROGEN FERTILIZATION ON BLACK WALNUT-- GROWTH, LOG QUALITY, AND WOOD ANATOMY

By
ROBERT R. MAEGLIN, Technologist
HIRAM HALLOCK, Technologist
FRANK FREESE, Statistician
and
KENT A. McDONALD, Technologist

Forest Products Laboratory,[1] Forest Service
U.S. Department of Agriculture

6 10 9 Forest Service research paper, 11 1977 12 14p. 14 FSRP-FPL-294

INTRODUCTION

Since 1939 when Mitchell and Chandler published their pioneering work on fertilizing hardwood trees many researchers have studied the effects of various fertilizers on many different species. Most of the research evaluated volume growth without concern for log or wood quality. In these studies, many have been on black walnut (Juglans nigra L.) (Thomson and McComb, 1962; Jones and Curlin, 1968; Schneider et al., 1968; Auchmoody and Filip, 1973; Burke and Williams, 1973; and von Althen, 1973).

Because of the value of black walnut and the large amount of interest in the species, in 1965 the U. S. Forest Products Laboratory undertook a stud[illegible] the effect of nitrogen fertilization on [illegible] walnut growth, log quality, and w[illegible]ality. The results are reported here af[illegible] [illegible] years of growth and three applications of ammonium nitrate fertilizer.

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

METHODS AND MATERIALS

Location and Site

A 40-acre tract in southwestern Wisconsin (Grant County) was selected for study. Two sites were chosen representative of (1) alluvial bottomlands and (2) well drained uplands. The upland site was 100 to 200 feet higher than the bottomland site.

The bottomland site had soils of colluvial origin, classified in the Chaseburg silt loam series. These soils are deep, rich, fine-textured, and well drained. The upland site had residual soils of the Fayette silt loam series. These soils, overlying a fractured limestone parent material, varied in depth from 1 to 4 feet. Results of soil analyses are shown in table 1.

Tree Selection

On each site, 10 pairs of trees as closely matched as possible for diameter at breast height (DBH), total height, crown size, and stand density were selected for investigation. Small-diameter trees, although suppressed, were included to evaluate the effects of fertilization on crown position, to balance diameter

141 700

nt

distribution, and to simulate the effects of broadcast fertilizer application. The trees were about 40 years old when selected and were the result of logging in the early 1920's. One tree per pair was selected to be fertilized; the other was held unfertilized for use as a control. The trees were so spaced that fertilization of one would not affect another.

Fertilization

Based on the work of Mitchell and Chandler (1939), a fertilization rate of 500 pounds per acre of elemental nitrogen was chosen. Ammonium nitrate (33 pct elemental N) was spread by hand in a circular area around each tree selected for fertilization. The area to be fertilized corresponded to a calculated crown diameter estimated by the formula 8/3 DBH - 5 = crown diameter, where DHB = diameter at breast height in inches and crown diameter is in feet.

The original fertilization was done in May 1965; subsequent fertilizing was done in May 1969 and 1972. The same rate of application was used each time.

Particular care was taken not to disturb the natural surroundings that might cause the sample trees to be released or suppressed.

Measurements

Trees were initially measured before growth began in 1965 for DBH, total height, diameter outside bark (DOB) at 17 feet, estimated number of 16-foot logs, clear bole length, and crown ratio (table 2).

The bark at 4.5 feet above ground was smoothed and a permanent yellow band painted around the tree to mark the DBH point for consistent measurement.

The butt 16-foot section above a 1-foot stump of each tree was carefully diagramed (Bulgrin, 1962) to provide an exact record of all external indicators of log quality prior to fertilization.

After leaf fall of each growing season and before commencement of growth the following season, the diameter of each tree was measured and recorded. Periodically, external log quality indicators were noted.

In early September 1965, leaf samples were taken for chemical analysis from the midheight of each tree's crown. A shotgun was used to fell branches.

At the end of the 10-year period, all trees were measured for DBH, total height, crown ratio, DOB at 17 feet, and each butt log was re-diagramed. Sample increment cores were taken at 8.7 feet from four trees (two bottomland, two upland; one fertilized and one control from each site). The 8.7-foot boring point permits an 8-foot veneer bolt plus trim, without borer damage. The cores were selected for intrinsic wood property analysis.

Measurements obtained from the increment cores were tissue proportions, fiber length, cell wall thickness, and cell diameters.

Analyses of variance were used to evaluate the significance of differences in growth within sites and foliar nitrogen within and between sites. Other data were analyzed graphically or by tabulation.

RESULTS AND DISCUSSION

Growth

Figure 1 shows the trends in average diameter over the 10-year study period. Comparisons of periodic diameter growth are summarized in tables 2 and 3. On the upland site, diameter growth of fertilized trees was greater than that of controls, but the difference was not statistically significant at 0.05 level of probability over the years of study or during any intermediate periods.

On the bottomland site, in all except the first growth period, control trees had consistently greater diameter growth and the differences were statistically significant (0.05 level of probability) or highly significant (0.01 level of probability). Expressing growth as a percent of initial diameter or as radius squared did not alter any of the results.

The inclusion of two small-diameter suppressed trees in the analyses may have affected the significance of growth differences on the upland site. On the bottomland, two suppressed trees were severely storm damaged, and eliminated from the analyses.

There were no significant differences between treatments in either height growth or first 16-foot log volume growth.

Foliar Nitrogen

In early September of 1965 before leaf fall

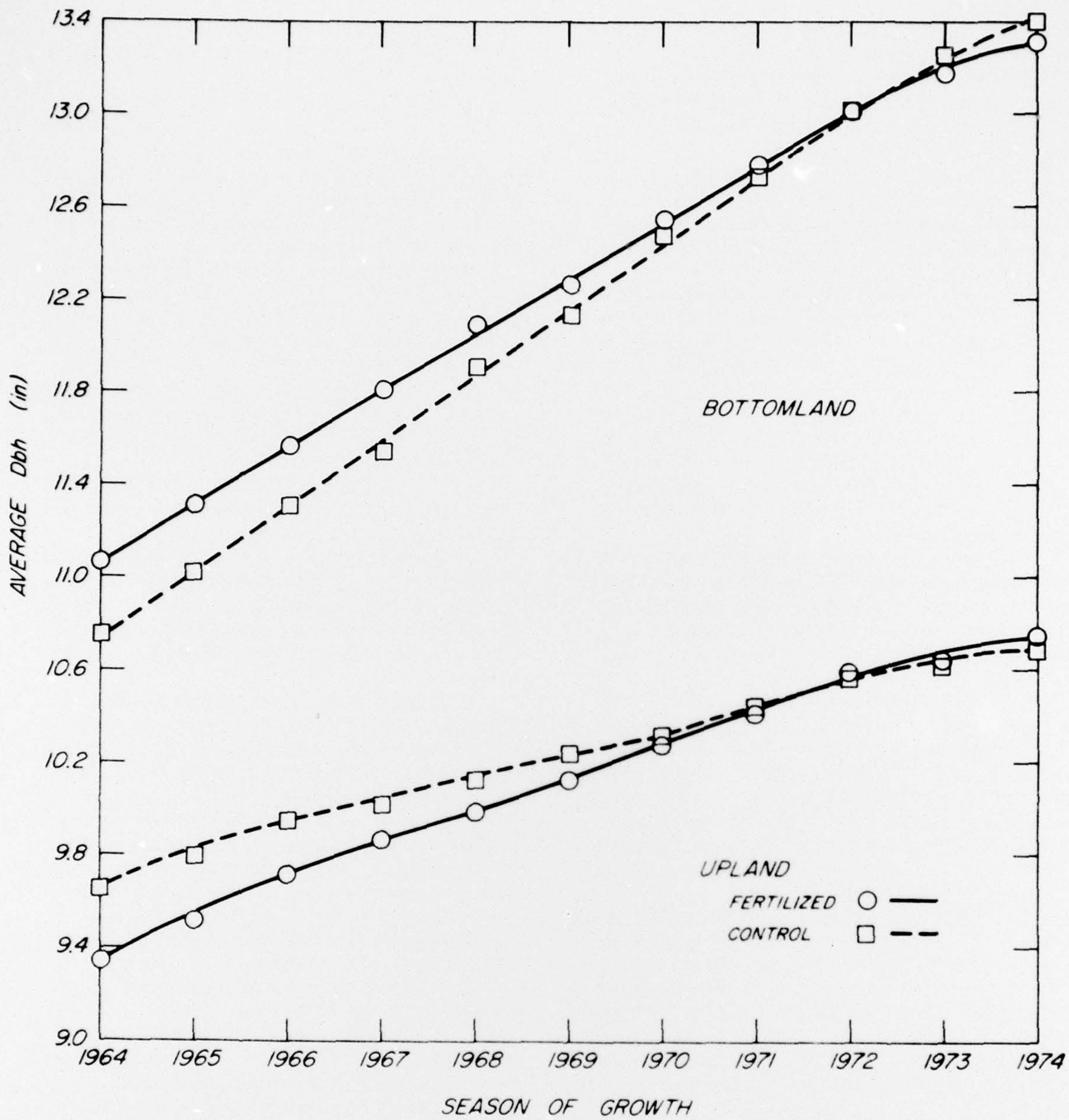


Figure 1.--Average diameter growth at breast height for upland and bottomland, fertilized, and control trees for 10 years, 1965-1974.
(M 144 557)

began, foliar samples were taken to assess the nitrogen uptake and to evaluate the total nutrient status of the trees (table 4). The foliage from the upland site showed a significantly lower level of nitrogen than did that from the bottomland site. The upland control trees were on the average 0.66 percentage points lower in nitrogen than the bottomland control trees (upland, 2.52 pct; bottomland, 3.18 pct). However, the uptake of nitrogen by the fertilized trees was much greater on the upland site (assuming that the fertilized trees were at

about the same average level of foliar nitrogen as the control trees prior to fertilizing). The upland trees showed a highly significant, more than 18 percent increase, in foliar nitrogen; whereas, the bottomland trees showed a non-significant 6-percent increase.

Finn (1966) reports foliar nitrogen levels for 17 black walnut stands, that ranged from 1.2 to 3.4 percent. For black walnut trees grown in sand culture, he showed a range from 2.9 to 3.5 percent.

The data in table 4 indicate foliar nitrogen levels for upland trees are in the upper middle of the range, whereas levels for the bottomland trees are in the very top of the ranges shown by Finn.

The low level of additional nitrogen uptake by the bottomland trees indicates a lack of need for additional nitrogen. The authors believe that the trees were consuming nitrogen at a luxury level--to the point of restricting additional growth.

Phares and Finn (1971) report no probable response from adding nitrogen when foliar level is above 2.6 percent, some response at foliar levels of 2.0 to 2.6 percent, and a likely response at levels below 2.0 percent foliar nitrogen.

Adding nitrogen generally affects the crown (foliage) of a plant. Russell (1961) states that "...over a considerable range of nitrogen supply for many crops the amount of leaf area available for photosynthesis is roughly proportional to the amount of nitrogen supplied." Because of this relationship, it was thought that crown ratio might reflect the response of the trees to fertilization.

On both sites average crown ratio increased for all trees between 1965 and 1975. The upland fertilized trees responded with a greater, although not significant, increase than did the controls. The bottom-land control trees showed a larger increase than did the fertilized trees, but again it was not significant. These findings are consistent with diameter growth trends.

Other foliar nutrient levels shown in table 4 are sufficient for satisfactory growth.

Growth Differences Between Sites

The differences in growth patterns between the upland and the bottomland sites may be explained in part by the physical terrain and the soils. The fairly steep 15-percent slope of the upland site is believed responsible for both a lower availability of moisture and a lower level of nutrients due to drainage and leaching. The bottomland, however, is believed to have abundant natural nutrients and good moisture availability on its gentle (less than 2 pct) slope.

In accordance with Liebig's law, growth increases with additions of a limiting nutrient until it ceases to be limiting. Nitrogen on the upland site was believed to be limiting, although not critically, as shown by the foliar analysis. Additions of nitrogen to the trees resulted in increased growth.

On the bottomland, where the nutrient levels were high, none of the nutrients was limiting. The addition of nitrogen is believed to have resulted in an excess that caused the retardation of growth.

Wolter (1963) has shown, *in vitro,* that excess nitrogen in the presence of high levels of phosphorous, potassium, or both will reduce growth.

Both soil and foliar analyses showed that high levels of phosphorous and potassium were present on the bottomland site.

Phares[2] reports a similar retardation of black walnut growth in Indiana. Trees of a 60-80-year-old, sawlog-sized stand growing on a fertile bottomland draw had less growth on nitrogen-fertilized trees than on control trees.

Both soil and foliar analyses should be made prior to fertilizing black walnut, especially for high-quality bottomland sites. Table 5 shows foliar nutrient levels for various cultural and growth conditions.

The foliar nutrient levels shown by Finn (1966) for sand culture with nutrient solutions should be truly optimal. In table 4 we find that half of the bottomland control trees are below the optimum 3.14 percent nitrogen given by Finn; whereas, 9 of the 10 fertilized bottomland trees exceeded the optimum.

Soil nutrient levels are more difficult to assess than are foliar levels because of the artificial extraction methods used. The nutrient solution optima for sand culture shown in table 6 are not directly comparable to the other values, but they do afford some indication of balance between nutrients.

Intrinsic Wood Properties

Differences in anatomical proportions and dimensions for both control and fertilized trees and for pre- and post-fertilization periods are given in table 7.

---

[2] Unpublished data, U.S. Forest Service, North Central Forest Experiment Station, Carbondale, Ill.

A comparison of the data before and after fertilizing shows that fertilizer had a minimal effect on the anatomy of the wood. The changes that occurred appear for both the fertilized and the control trees. Englerth (1966) indicates that large differences in growth rate have little effect on machining properties of black walnut. The anatomical differences reported in this study are mostly related to growth rate; therefore they should not affect machining properties. These data may be compared with that by others for black walnut [Stark (1953), Boyce et al. (1970), and Hiller et al. (1972)].

Log Quality

Overall log quality on the bottomland site, as measured by surface indicators, increased on both the fertilized and the control trees. There were no new sprouts after 10 years, and all trees had grown sufficiently to cover even more deeply the overgrown knots that were initially present.

On the upland site, the control trees had 14 new twigs on the bottom 16-foot logs of five of the trees; twigs lower the potential quality of logs. Two of the fertilized trees each had a single new twig. The difference in the occurence of twigs between the fertilized and the control trees is highly significant. Although other factors may have caused the increased sprouting on the control trees; no factor was apparent other than the lack of fertilization.

CONCLUSIONS

Results of this study indicate no negative effects on the quality of logs or wood of black walnut fertilized with ammonium nitrate. Fertilized upland trees had fewer sprouts than did control trees, indicating no loss of net log quality.

Reduced growth rates on the naturally fertile bottomland due to adding nitrogen demonstrate the need to analyze both foliage and soil for nitrogen, phosphorus, and potassium before fertilizing. High fertility sites should not be fertilized.

LITERATURE CITED

Althen, von F. W.
1973. Fertilization of juvenile hardwoods. *In* For. Fert. Symp. Proc., USDA For. Serv., Gen. Tech. Rept. NE-3, p.183-187.

Auchmoody, L. R., and S. M. Filip.
1973. Forest fertilization in the eastern United States: Hardwoods. *In* For. Fert. Symp. Proc., USDA For. Serv. Gen. Tech. Rept. NE-3, p. 211-225.

Boyce, S. G., M. Kaiser, and C. F. Bey.
1970. Variations of some wood features in five black walnut trees. For. Sci. 16(1): 95-100.

Bulgrin, E. H.
1962. Hardwood tree diagraming manual. USDA For. Serv. Cent. States For. Exp. Sta., Man. No. 1, p. 49.

Burke, R. D., and R. D. Williams.
1973. Establishment and early culture of plantations. *In* Black walnut as a crop. Black Walnut Symp., USDA For. Serv., Gen. Tech. Rept. NC-4, p. 36-41.

Englerth, G. H.
1966. Machining and other properties of fast- versus slow-grown trees. *In* Black Walnut Culture, Walnut Workshop Proc., Aug. 2, 3, 1966. Carbondale, Ill., p. 77-82.

Finn, R. F.
1966. Mineral nutrition. *In* Black Walnut Culture, Walnut Workshop Proc., Aug. 2, 3, 1966. Carbondale, Ill., p. 35-41.

Hiller, C. H., F. Freese, and D. M. Smith.
1972. Relationships in black walnut heartwood between color and other physical and anatomical characteristics. Wood and Fiber 4(1):38-42.

Jones, H. D. III, and J. W. Curlin.
1968. The role of fertilizers in improving the hardwoods of the Tennessee valley. *In* For. Fert. Symp. 1967. TVA, Knoxville, Tenn. For. Fert. Symp.: Theory and practice. 1967. p. 185-190.

Mitchell, H. L., and R. F. Chandler Jr.
1939. The nitrogen nutrition and growth of certain deciduous trees of northeastern United States. Black Rock For. Bull. 11, p. 94.

Phares, R. E., and R. F. Finn.
1971. Using foliar analysis to help diagnose nutrient deficiences in black walnut. 62nd Ann. Rep. North. Nut Growers Assoc., Carbondale, Ill.

Russell, E. W.
1961. Soil conditions and plant growth. 9th ed., p. 688. J. Wiley and Sons, Inc., New York.

Stark, E. W.
1953. Wood anatomy of the juglandaceae indigenous to the United States. Sta. Bull. 595, Purdue Univ. Agric. Exp. Sta., Lafayette, Ind., p. 42.

Thomson, G. W., and A. L. McComb.
1962. Growth of plantation black walnut in relation to pH and certain chemical factors of the soil. For. Sci. 8(4):322-333.

Wolter, K. E.
1964. *In vitro* cultivation of ash, aspen, and pin oak callus tissue. Dissert. Abstr. 24(12, pt. 1):4895.

Schneider, G., G. Khattak, and J. N. Bright.
1970. Modifying sites for the establishment of black walnut. *In* Tree growth and forest soils. North Am. For. Soil Conf. Proc. (3 d), Raleigh, N. C., Youngberg, C. T., and C. B. Davey., eds., 1968. Oregon State Univ. Press, Corvallis, p. 155-160.

Table 1.--Ranges and means of available soil nutrients and other soil properties for test sites

	Soil property						
	Total nitrogen	Available phosphorus	Available potassium	Exchangeable calcium	Exchangeable magnesium	Organic matter	pH
	Pct	Ppm	Ppm	Ppm	Ppm	Pct	
				UPLAND			
Range	--	42.5-117.5	42.5-87.5	600-3,400	206-905	7-11	5.8-6.6
Mean	0.17	68.2	61.5	1,330	433	9	6.2
				BOTTOMLAND			
Range	--	67.5-90.0	62.5-167.5	2,625-4,500	605-925	6-13	6.2-7.0
Mean	.21	79.4	130.3	3,306	716	9	6.6

Table 2.--Initial dimensions and diameter growth for 1965-1975

Pair No.	1965 diameter at breast height		Diameter growth at breast height		1965 diameter at 17 feet		Diameter growth at 17 feet		Potential number of 16-foot logs		1965 clear bole length	
	Fertilized	Contol	Fertilized	Control	Fertilized	Control	Fertilized	Control	Fertilized	Control	Fertilized	Control
	In.	In.	In.	In.	In.	In.	In.	In.	--	--	Ft	Ft
					UPLAND							
1	9.7	9.3	1.6	0.7	8.5	8.5	1.6	0.6	2.5	2.5	28	25
2	12.2	12.6	1.3	1.0	10.1	11.9	1.5	1.2	1.0	2.0	14	35
3	9.8	10.7	1.0	1.2	9.1	8.5	.4	2.1	1.5	1.5	22	20
4	11.8	13.0	1.8	1.6	9.6	12.2	2.0	1.6	1.5	1.5	18	30
5	10.0	10.9	2.8	1.1	9.3	9.0	2.3	1.8	1.5	2.0	28	20
6	6.4	8.3	.3	.7	5.5	7.8	.3	.4	2.0	1.5	20	20
7	7.6	6.4	.4	.7	7.0	5.4	.0	.6	1.5	1.5	25	24
8	9.7	8.8	1.3	.8	8.6	7.4	.9	.8	1.0	2.0	22	24
9	6.2	7.1	.3	.4	5.2	6.2	.3	.3	1.5	1.0	20	18
10	10.2	10.0	2.8	1.4	8.9	8.3	2.8	1.3	2.0	2.0	25	28
Ave.	9.4	9.7	1.4	1.0	8.2	8.5	1.2	1.1	1.6	1.8	22	24
					BOTTOMLAND[1]							
1	8.9	8.8	2.4	2.5	8.4	8.6	2.0	2.7	2.0	1.0	28	16
2	13.7	12.3	2.8	3.0	11.1	11.3	2.9	2.8	1.5	2.0	16	30
3	13.9	12.8	2.6	2.9	13.3	11.0	2.4	2.6	2.5	2.0	22	26
4	12.5	12.4	3.0	3.8	10.9	11.4	2.6	2.9	2.0	1.5	30	22
5	3.8	5.4	--	--	3.0	4.6	--	--	--	--	--	--
6	12.9	12.1	2.6	2.6	12.5	10.6	2.6	2.6	1.5	2.0	22	20
7	11.4	12.8	2.6	3.0	10.3	12.0	2.3	2.7	1.5	2.5	28	28
8	6.8	5.5	.4	.8	6.5	5.1	.1	.7	--	--	24	18
9	13.7	13.0	3.0	3.6	11.9	11.8	2.4	3.3	2.0	2.5	30	40
10	13.0	12.4	1.9	2.6	11.3	11.8	1.8	2.3	1.5	2.5	22	35
Ave.	11.9	11.3	2.3	2.8	10.7	10.4	2.1	2.5	[2]1.8	[2]2.0	25	26

[1]Trees 10 and 11 were lost in a storm and are not included in averages (n = 9).
[2]Trees 17 and 19 did not have a 16-foot log and were not included in averages (n = 8).

Table 3.--Periodic growth relationships between fertilized and control black walnut trees

Period	Average diameter growth (fertilized)	Average diameter growth (control)	Average diameter growth difference (fertilized - control[1])
	In.	In.	In.
		UPLAND	
1965-1968	0.62	0.45	0.17 NS
1969-1971	.42	.31	.11 NS
1972-1975	.32	.24	.08 NS
1965-1975	1.36	1.00	.36 NS
		BOTTOMLAND	
1965-1968	1.06	1.17	-.11 NS
1969-1971	.72	.86	-.14**
1972-1975	.59	.73	-.14*
1965-1975	2.37	2.76	-.39**

[1]NS = Not significant at 0.05 level of probability; * = significant at 0.05 level of probability; and ** = significant at 0.01 level of probability.

Table 5.--Foliar nutrient requirements for suitable black walnut growth

Source	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
	Percent foliar nutrients of dry leaf weight				
Finn (1966)[1]	2.26	0.22	1.23	1.60	0.46
Finn (1966)[2]	3.14	.36	1.39	1.27	.45
Schneider et al. (1968)[3]	2.56	.20	.96	1.67	.38
Thomson and McComb (1962)[4]	2.52	.21	1.95	2.56	.69
Bottomland fertilized (this study)	3.36	.27	1.80	--	--

[1]Mean values for 17 sites across range of black walnut (from table 5).
[2]Optimum for sand culture and nutrient solution (from table 1).
[3]Fertilized 1-0 seedlings after 1-year outplanting.
[4]Averaged data for 5 sites with highest site index.

Table 4.--Foliar analysis after first application of 500 pounds per acre of nitrogen

Fertilized					Control				
Tree number	Initial diameter at breast height	N	P	K	Tree number	Initial diameter at breast height	N	P	K
		Pct	Pct	Pct			Pct	Pct	Pct
				UPLAND					
3	9.7	3.10	0.22	1.64	1	9.3	2.47	0.23	1.83
4	12.2	3.20	.29	1.62	2	12.6	2.74	.29	2.26
5	9.8	2.72	.19	2.10	6	10.7	2.44	.27	1.60
8	11.8	3.19	.30	1.94	7	13.0	2.50	.28	1.83
10	10.0	3.00	.25	1.94	11	10.5	2.66	.24	1.90
12	6.4	3.06	.21	1.52	14	8.3	2.88	.34	1.98
15	7.6	3.12	.22	2.14	17	6.4	2.30	.33	2.26
18	9.7	2.70	.31	1.82	19	8.8	2.06	.47	2.33
20	6.2	2.84	.24	2.26	22	7.1	2.55	.39	1.86
23	10.2	2.88	.21	2.28	21	10.0	2.60	.34	2.18
Ave.	9.4	2.98	.24	1.93	Ave.	9.7	2.52	.32	2.00
				BOTTOMLAND					
1	8.9	3.40	.28	1.40	3	8.8	3.18	.34	1.90
2	13.7	3.23	.28	1.38	5	12.3	2.90	.30	1.98
7	13.9	3.53	.24	1.62	6	12.8	2.38	.25	2.24
12	12.5	3.22	.26	1.86	8	12.4	3.20	.12	1.56
10	3.8	3.68	.26	2.14	11	5.4	4.36	.26	1.83
14	12.9	3.64	.29	1.86	13	12.1	2.90	.27	2.04
16	11.4	3.63	.23	2.02	15	12.8	3.04	.24	2.10
17	6.8	2.32	.28	2.10	19	5.5	3.39	.29	1.75
18	13.7	3.58	.26	1.78	20	13.0	3.40	.33	1.90
22	13.0	3.40	.31	1.86	21	12.4	3.08	.25	1.58
Ave.	11.1	3.36	.27	1.80	Ave.	10.8	3.18	.26	1.89

Table 6.--Soil nutrient requirements for suitable black walnut growth

Source	Soil nutrients					
	Total nitrogen	Available phosphorus	Exchange-able potassium	Exchange-able calcium	Exchange-able magnesium	Organic matter
		Ppm	Ppm	Ppm	Ppm	Pct
Wilde (1958)[1]	0.10 (pct)	25	62	600	150	4
Finn (1966)[2]	200-300 (ppm)	100-180	200-450	180-240	80-120	--
Bottomland (this study)		79	130	3,306	716	9

[1]Minimum soil requirements for suitable growth (p. 419).
[2]Optimum growth in sand culture and nutrient solution (from table 2).

Table 7.--Intrinsic wood properties for

Trees	Pre-1965				Post-1965				Pre-1965		
	Percent vessel	Percent fiber	Percent axial paren-chyma	Percent rays	Percent vessel	Percent fiber	Percent axial paren-chyma	Percent rays	Vessel lumen diameter	Vessel wall thick-ness	Vessel diameter radial
									Mm		
									UPLAND		
Fertilized											
Range	--	--	--	--	--	--	--	--	116-154	4-5	124-165
Mean	11.8	74.1	4.2	9.9	11.8	69.4	6.6	12.2	136	4.4	140
Control											
Range	--	--	--	--	--	--	--	--	114-153	4-5	122-163
Mean	34.9	53.1	4.0	8.0	23.3	59.0	4.0	13.7	126	4.5	135
Upland Mean	23.3	63.6	4.1	9.0	17.6	64.2	5.3	13.0	131	4.4	138
									BOTTOMLAND		
Fertilized											
Range	--	--	--	--	--	--	--	--	158-214	4-5	166-224
Mean	20.8	69.7	6.0	3.4	20.1	65.2	5.0	9.7	181	4.7	190
Control											
Range	--	--	--	--	--	--	--	--	156-211	3-5	162-220
Mean	18.6	70.5	2.3	8.6	18.0	70.1	4.6	7.3	183	4.0	191
Bottomland Mean	19.7	70.1	4.2	6.0	19.0	67.7	4.8	8.5	182	4.4	190
Overall Mean	21.5	66.8	4.2	7.5	18.3	66.0	5.0	10.8	156	4.4	164
Combined Mean	--	--	--	--	19.9	66.4	4.6	9.2	--	--	--

pre- and post-fertilization periods

Post-1965			Pre-1965			Post-1965			Pre-1965	Post-1965
Vessel lumen diameter	Vessel wall thick-ness	Vessel diameter radial	Fiber lumen diameter	Fiber wall thick-ness	Fiber diameter radial	Fiber lumen diameter	Fiber wall thick-ness	Fiber diameter radial	Fiber length	Fiber length
------------	------------	------------	------------	------------	------------	------------	------------	------------	Mm	Mm
95-138	4-6	103-148	15-21	3-4	20-28	10-16	2-3	14-22	0.78-2.20	0.67-2.10
117	4.7	121	18	3.1	21	15	2.5	20	1.50	1.43
86-139	4-5	94-148	14-22	2-3	19-27	15-19	2-3	19-26	.66-1.88	.86-1.99
118	4.2	126	18	2.6	24	16	2.6	22	1.20	1.38
118	4.4	124	18	2.8	22	16	2.6	21	1.35	1.40
160-205	4-5	167-215	17-22	3-4	23-30	16-22	2-5	20-31	.94-2.83	1.03-2.38
177	4.3	185	20	3.4	27	16	3.0	22	1.65	1.57
156-208	4-5	164-218	17-21	2-3	22-27	16-22	2-3	19-27	.82-2.33	.86-2.45
183	4.4	191	19	2.5	24	18	2.2	23	1.46	1.51
180	4.4	188	20	3.0	26	17	2.6	22	1.56	1.54
149	4.4	156	19	2.9	24	16	2.6	22	1.46	1.47
152	4.4	160	--	--	--	18	2.8	23	--	1.46

U.S. Forest Products Laboratory.

Effect of nitrogen fertilization on black walnut--Growth, log quality, and wood anatomy, by Robert R. Maeglin, Hiram Hallock, Frank Freese, and Kent A. McDonald, Madison, Wis., FPL, 1977.
13 p. (USDA For. Serv. Res. Pap. 294)

Two 40-year-old black walnut stands, an upland and a bottomland, in southern Wisconsin were examined for effects of nitrogen treatment.

KEYWORDS: Nitrogen fertilizer, ammonium nitrate, black walnut, upland, bottomland, diameter, wood anatomy, log quality.

U.S. Forest Products Laboratory.

Effect of nitrogen fertilization on black walnut--Growth, log quality, and wood anatomy, by Robert R. Maeglin, Hiram Hallock, Frank Freese, and Kent A. McDonald, Madison, Wis., FPL, 1977.
13 p. (USDA For. Serv. Res. Pap. 294)

Two 40-year-old black walnut stands, an upland and a bottomland, in southern Wisconsin were examined for effects of nitrogen treatment.

KEYWORDS: Nitrogen fertilizer, ammonium nitrate, black walnut, upland, bottomland, diameter, wood anatomy, log quality.

U.S. Forest Products Laboratory.

Effect of nitrogen fertilization on black walnut--Growth, log quality, and wood anatomy, by Robert R. Maeglin, Hiram Hallock, Frank Freese, and Kent A. McDonald, Madison, Wis., FPL, 1977.
13 p. (USDA For. Serv. Res. Pap. 294)

Two 40-year-old black walnut stands, an upland and a bottomland, in southern Wisconsin were examined for effects of nitrogen treatment.

KEYWORDS: Nitrogen fertilizer, ammonium nitrate, black walnut, upland, bottomland, diameter, wood anatomy, log quality.

U.S. Forest Products Laboratory.

Effect of nitrogen fertilization on black walnut--Growth, log quality, and wood anatomy, by Robert R. Maeglin, Hiram Hallock, Frank Freese, and Kent A. McDonald, Madison, Wis., FPL, 1977.
13 p. (USDA For. Serv. Res. Pap. 294)

Two 40-year-old black walnut stands, an upland and a bottomland, in southern Wisconsin were examined for effects of nitrogen treatment.

KEYWORDS: Nitrogen fertilizer, ammonium nitrate, black walnut, upland, bottomland, diameter, wood anatomy, log quality.